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☐	L12	L11 and (correct$4 or compensat$4)	5
☐	L11	L10 and (Fourier or "ft" or "FFT")	5
☐	L10	L9 and (((amplitude with (modulation or modifying or modified or chang$4 or adjust$4 or alter$3 or modulat$4)) or "AM") with ((fast with spin with echo) or fse))	5
☐	L9	L8 and (k-space or kspace or "k space" or "kx" or "ky" or "kz" or "k.sub.x" or "k.sub.y" or "k.sub.z" or raw)	178
☐	L8	L7 and ((fast with spin with echo) or fse)	618
☐	L7	((amplitude with (modulation or modifying or modified or chang$4 or adjust$4 or alter$3 or modulat$4)) or "AM")	1279886
☐	L6	L5 and (correct$4 or compensat$4)	3
☐	L5	L4 and (Fourier or "ft" or "FFT")	3
☐	L4	L3 and (((amplitude with (modilation or modifying or modified or chang$4 or adjust$4 or alter$3)) or "AM") with((fast with spin with echo) or fse))	3
☐	L3	L2 and (k-space or kspace or "k space" or "kx" or "ky" or "kz" or "k.sub.x" or "k.sub.y" or "k.sub.z" or raw)	116
☐	L2	L1 and ((fast with spin with echo) or fse)	509
☐	L1	((amplitude with (modilation or modifying or modified or chang$4 or adjust$4 or alter$3)) or "AM")	1224320

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☐ 1. Document ID: US 6456071 B1

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L12: Entry 1 of 5 File: USPT Sep 24, 2002

US-PAT-NO: 6456071
DOCUMENT-IDENTIFIER: US 6456071 B1

TITLE: Method of measuring the magnetic resonance (=NMR) by means of spin echos

DATE-ISSUED: September 24, 2002

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Hennig; Jurgen	Freiburg			DE

US-CL-CURRENT: 324/307; 324/309, 324/311

Full | Title | Citation | Front | Review | Classification | Date | Reference | | | Claims | KWIC | Draw D

☐ 2. Document ID: US 6414487 B1

L12: Entry 2 of 5 File: USPT Jul 2, 2002

US-PAT-NO: 6414487
DOCUMENT-IDENTIFIER: US 6414487 B1

TITLE: Time and memory optimized method of acquiring and reconstructing multi-shot 3D MRI data

DATE-ISSUED: July 2, 2002

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Anand; Christopher K.	Chesterland	OH		
Halamek; James A.	Independence	OH		
Steckner; C. Michael	Richmond Heights	OH		

US-CL-CURRENT: 324/309; 324/307

Full | Title | Citation | Front | Review | Classification | Date | Reference | | | Claims | KWIC | Draw D

☐ 3. Document ID: US 5345176 A

L12: Entry 3 of 5 File: USPT Sep 6, 1994

US-PAT-NO: 5345176
DOCUMENT-IDENTIFIER: US 5345176 A

TITLE: Stabilized fast spin echo NMR pulse sequence with improved slice selection

DATE-ISSUED: September 6, 1994

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
LeRoux; Patrick L.	Gif/Yvette			FR
Hinks; Richard S.	Waukesha	WI		

US-CL-CURRENT: 324/309

Full | Title | Citation | Front | Review | Classification | Date | Reference | | | Claims | KWIC | Draw. D

☐ 4. Document ID: US 5315249 A

L12: Entry 4 of 5 File: USPT May 24, 1994

US-PAT-NO: 5315249
DOCUMENT-IDENTIFIER: US 5315249 A

TITLE: Stabilized fast spin echo NMR pulse sequence

DATE-ISSUED: May 24, 1994

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Le Roux; Patrick L.	Gif/Yvette			FR
Hinks; Richard S.	Waukesha	WI		

US-CL-CURRENT: 324/309; 324/307

Full | Title | Citation | Front | Review | Classification | Date | Reference | | | Claims | KWIC | Draw. D

☐ 5. Document ID: US 4684891 A

L12: Entry 5 of 5 File: USPT Aug 4, 1987

US-PAT-NO: 4684891
DOCUMENT-IDENTIFIER: US 4684891 A

TITLE: Rapid magnetic resonance imaging using multiple phase encoded spin echoes in each of plural measurement cycles

DATE-ISSUED: August 4, 1987

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Feinberg; David A.	Berkeley	CA		

US-CL-CURRENT: 324/309; 324/307

Full | Title | Citation | Front | Review | Classification | Date | Reference | | | Claims | KWIC | Draw D

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Term	Documents
CORRECT$4	0
CORRECT	957848
CORRECTA	145
CORRECTAB	10
CORRECTABIE	2
CORRECTABJE	1
CORRECTABL	4
CORRECTABLE	8812
CORRECTABLO	1
CORRECTABLT	1
CORRECTABLY	315
(L11 AND (CORRECT$4 OR COMPENSAT$4)).PGPB,USPT,USOC,EPAB,JPAB,DWPI,TDBD.	5

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Previous Page Next Page Go to Doc#

L12: Entry 1 of 5 File: USPT Sep 24, 2002

DOCUMENT-IDENTIFIER: US 6456071 B1
TITLE: Method of measuring the magnetic resonance (=NMR) by means of spin echos

Brief Summary Text (6):
Such a deviation can occur either through technical facts or be artificially produced, e.g. in applications on human beings for keeping the values of the radiated radio frequency energy within tolerable limits (SAR=specific absorption rate). Literature proposed a series of measures for limiting the corresponding signal losses. This includes on the one hand the so-called Carr-Purrcell-Meiboom-Gill method (D2) wherein by an appropriate displacement of the pulse phase between excitation and refocusing pulses, partial automatic compensation of the refocusing pulses is effected.

Brief Summary Text (9):
In applications of analytical NMR spectroscopy, improvements through different phase cycles such as MLEV16 or XY16 are used (D6). These serve mainly for compensating residual small errors in refocusing pulses with a flip angle of approximately 180.degree..

Brief Summary Text (46):
According to the basic principle, that radio frequency pulses having a complicated amplitude and phase profile (as used e.g. for slice selection in NMR tomography) can be represented as a sequence of short pulses with discrete flip angle, equations [9]-[11] are valid analogously also for pulse sequences with amplitude and/or phase-modulated pulses. Additionally, it should be noted that the phase of the central refocusing pulse was defined to be 0.degree. and does not necessarily need to correspond to the reference phase of magnetization. Coordination transformation of equations [9]-[11] corresponding to equation [3] makes the refocusing relation of equation [11] also valid for any phases of the central pulse if corresponding transformation is carried out also for the other pulses.

Brief Summary Text (67):
With this modification, the amplitude of the (2n+1)th echo can be reproduced to the completely refocused value (=1) for any .alpha..sub.1 . . . . .alpha..sub.n. When using such a sequence in MR tomography corresponding to the RARE method, the contrast of the image is essentially given by the intensity of the echo which represents the center of the k space in the phase encoding direction.

Brief Summary Text (69):
In particular, for so-called multi-contrast methods wherein phase encoding is carried out such that at least the center of the k space is read several times and at different echo times, the principle according to equation [12] can be repeated several times even during an echo train such that several hyper-echos can be formed in one echo train.

Brief Summary Text (85):
The application, as described, onto measuring methods in MR imaging are merely illustrative. A large number of measuring sequences in analytical NMR--mainly multiple-dimensional Fourier spectroscopy--such as COSY, NOESY, INEPT, INADEQUATE etc.--to name only some of the current sequences, is based on a plurality of

repetitions of multi-pulse sequences. With all these sequences, balanced magnetization can be achieved more rapidly through formation of a hyper-echo with subsequent flip back pulse and thus reduction of the measuring time and/or increase of the signal-to-noise ratio. If in such sequences, pulses are applied to different nuclei, formation of hyper-echos onto all nuclei concerned is advantageous.

Brief Summary Text (102):
Spin ensembles which move incoherently due to molecular diffusion experience an amplitude change due to the incoherent dephasing, which depends on the diffusion constant and will also attenuate the amplitude of the subsequent hyper-echo. Formation of the hyper-echo per se will not be influenced by diffusion.

Brief Summary Text (105):
The embodiments shown in FIGS. 8A through 8C of a modified hyper-echo sequence are again exemplarily. Literature (see e.g. (D9), (D10)) shows a large number of method steps which include concrete change of the signal phase and/or amplitude and can be applied also in a hyper-echo sequence.

Detailed Description Text (19):
FIG. 8C shows that a motion-dependent change of the signal phase and thus change of the amplitude of the hyper-echo can be effected already merely through corresponding magnetic field gradients alone in an otherwise unchanged hyper-echo sequence.

Detailed Description Text (22):
LITERATURE (D1) Hahn E L, Spin Echoes, Phys.Rev. 80:580-594 (1950) (D2) Meiboom S, Gill D, Modified Spin-Echo Method for Measuring Nuclear Relaxation Times, Review of Scientific Instruments, 29:688-691 (1958) (D3) Hennig J, Multiecho Imaging Sequences with Low Refocusing Flip Angles, J.Magn.Reson., 78:397-407 (1988) (D4) Le Roux P, Hinks R S, Stabilization of echo amplitudes in FSE sequences, Magn Reson Med. 30:183-90 (1993) (D5) Alsop D C, The sensitivity of low flip angle RARE imaging, Magn Reson Med. 37:176-84 (1997) (D6) Gullion T, Baker D E, Conradi M S., J.Magn.Reson. 89, 479 (1990) (D7) van Uijen C M, den Boef J H, Driven-equilibrium radiofrequency pulses in NMR imaging, Magn Reson Med. 1984 Dec;1(4):502-7. (D8) Hennig J, Thiel T, Speck O, Improved Sensitivity to Overlapping Multiplet Signals in in vivo Proton Spectroscopy Using a Multiecho Volume Selective (CPRESS-) Experiment, Magn Reson Med. 37: 816-20 (1997) (D9) Haase A, Snapshot FLASH MRI. Applications to T1, T2, and chemical-shift imaging, Magn Reson Med. 13:77-89 (1990) (D10) Norris D G, Ultrafast low-angle RARE: U-FLARE, Magn Reson Med. 17: 539-542 (1991)

Other Reference Publication (4):
Le Roux P. Hinks RS, Stabilization of echo amplitudes in FSE sequences, Magn Reson Med. 30:183-90 (1993).

Previous Doc Next Doc Go to Doc#

L12: Entry 3 of 5 File: USPT Sep 6, 1994

DOCUMENT-IDENTIFIER: US 5345176 A
TITLE: Stabilized fast spin echo NMR pulse sequence with improved slice selection

Abstract Text (1):
A fast spin echo NMR pulse sequence is modified to stabilize the magnitude of early NMR echo signals produced during each shot. Stabilization is accomplished by modifying the amplitude of the nutation angle produced in the spins by the corresponding RF refocusing pulses. This stabilization is relaxed for the first RF refocusing pulse so that its maximum RF power can be reduced relative to that of the other RF refocusing pulses and the bandwidth thereof increased to improve the slice select profile.

Parent Case Text (2):
This is a continuation-in-part of co-pending U.S. patent application Ser. No. 07/920,952, filed on Jul. 28, 1992 and entitled "Stabilized Fast Spin Echo NMR Pulse Sequence" now U.S. Pat. No. 5,315,249.

Brief Summary Text (2):
The field of the invention is nuclear magnetic resonance imaging methods and systems. More particularly, the invention relates to the reduction of image artifacts in fast spin-echo (FSE) pulse sequences by producing RF refocusing pulses which stabilize the magnitude of the acquired spin echo signals.

Brief Summary Text (10):
Both of these "fast spin echo" imaging methods involve the acquisition of multiple spin echo signals from a single excitation pulse in which each acquired echo signal is separately phase encoded. Each pulse sequence, or "shot," therefore results in the acquisition of a plurality of views and a plurality of shots are typically employed to acquire a complete set of image data. For example, a RARE pulse sequence might acquire 8 or 16 separate echo signals, per shot, and an image requiring 256 views would, therefore, require 32 or 16 shots respectively.

Brief Summary Text (11):
It is well known that the RARE sequence, and particularly its slice selective implementation, suffers from a non-steady state behavior in the first NMR echo signals acquired during each shot. This is particularly true when the selective RF refocusing pulses are not exactly 180.degree.. In our copending U.S. patent application Ser. No. 07/920,952, filed on Jul. 28, 1992 and entitled "Stablized Fast Spin Echo NMR Pulse Sequence" we describe a technique for altering the nutation angles in successive RF refocusing pulses in order to stabilize the early NMR echo signals acquired during the RARE sequence. When applied to selective RF refocusing pulses this not only affects their amplitude, but also their shape. As a result, to provide perfectly stablized signals very large RF excitation fields must be produced if the proper shape of the selected slice is to be maintained. Particularly when the first spin echo signal is fully stabilized in a three-dimensional acquisition, the desired thickness and shape of the slice cannot be achieved with the RF power available on commercial NMR systems.

Brief Summary Text (13):
The present invention relates to an improved fast spin echo pulse sequence in which

the magnitude of an acquired series of NMR spin-echo signals is stabilized by shaping the RF refocusing pulses which produce them. More particularly, in a fast spin echo pulse sequence one or more RF refocusing pulses in a series are modified such that the magnitudes of their corresponding NMR spin-echo signals do not significantly oscillate, and the first RF refocusing pulse in the series is further modified to reduce the magnitude of its corresponding NMR spin-echo signal a predetermined amount. By modifying the first RF refocusing pulse it can be produced with the bandwidth and RF power needed to provide the desired slice, or slab, selection; and because the magnitude of the corresponding NMR spin-echo signal is reduced by a predetermined amount, it can be properly compensated in the image reconstruction process.

Drawing Description Text (4):
FIG. 3 is a graphic representation of a fast spin-echo pulse sequence;

Drawing Description Text (6):
FIG. 5 is a graphic representation of the RF refocusing pulse magnitude required for each RF refocusing pulse in the FSE pulse sequence of FIG. 3 to provide stabilized NMR echo signals according to the present invention; and

Detailed Description Text (2):
Referring first to FIG. 1, there is shown in block diagram form the major components of a preferred NMR system which incorporates the present invention and which is sold by the General Electric Company under the trademark "SIGNA". The overall operation of the system is under the control of a host computer system generally designated 100 which includes a main computer 101 (such as a Data General MV7800). The computer has associated therewith an interface 102 through which a plurality of computer peripheral devices and other NMR system components are coupled. Among the computer peripheral devices is a magnetic tape drive 104 which may be utilized under the direction of the main computer for archiving patient data and images to tape. Processed patient data may also be stored in an image disc storage device designated 110. The function of image processor 108 is to provide interactive image display manipulation such as magnification, image comparison, gray-scale adjustment and real-time data display. The computer system is provided with a means to store raw data (i.e. before image construction) utilizing a disc data storage system designated 112. An operator console 116 is also coupled to the computer by means of interface 102 and provides the operator with the means to input data pertinent to a patient study as well as additional data necessary for proper NMR system operation, such as calibrating, initiating and terminating scans. The operator console is also used to display images stored on discs or magnetic tape.

Detailed Description Text (6):
The gradient coil assembly 136 and the RF transmit and receiver coils 138 are mounted within the bore of the magnet utilized to produce the polarizing magnetic field. The magnet forms a part of the main magnet assembly which includes the patient alignment system 148. A shim power supply 140 is utilized to energize a shim coil associated with the main magnet and which are used to correct inhomogeneities in the polarizing magnet field. In the case of a superconductive magnet, the main power supply 142 is utilized to bring the polarizing field produced by the magnet to the proper operating strength and is then disconnected. The patient alignment system 148 operates in combination with a patient cradle and transport system 150 and patient positioning system 152. To minimize interference from external sources, these NMR system components are enclosed in an RF-shielded room generally designated 144.

Detailed Description Text (11):
Referring particularly to FIG. 3, a conventional fast spin echo NMR pulse sequence, known as a 2DFT RARE sequence is shown. For clarity, only four echo signals 301-304 are shown in FIG. 3, but it can be appreciated that more are produced and acquired.

These NMR echo signals are produced by a 90.degree. RF excitation pulse 305 which is generated in the presence of a G.sub.z slice select gradient pulse 306 to provide transverse magnetization in a slice through the patient. This transverse magnetization is refocused by each selective RF refocusing pulse 307 to produce the NMR spin echo signals 301-304 that are acquired in the presence of G.sub.x readout gradient pulses 308. Each NMR spin echo signal 301-304 is separately phase encoded by respective G.sub.y phase encoding pulses 309-313. The magnitude of each phase encoding pulse is different, and it is stepped through 256 values to acquire 256 separate views during a complete scan. This enables an image having 256 separate pixels in the y direction to be reconstructed. Each NMR spin echo signal is acquired by digitizing 256 samples of each signal. As a result, at the completion of a scan for one image, 16 shots (256/16=16) of the pulse sequence of FIG. 3 have been executed and a 256 by 256 element array of complex numbers has been acquired An image is reconstructed by performing a 2D Fourier transformation on this image data array and then calculating the absolute value of each resulting complex element. A 256 by 256 pixel image is thus produced in which the brightness of each pixel is determined by the magnitude of its corresponding element in the transformed array.

Detailed Description Text (12):
Referring still to FIG. 3, the T2 decay in the NMR spin echo signals 301-304 is illustrated by the dashed line 315. The rate of decay is different for different tissue types and a common strategy in FSE NMR imaging is to enhance the contrast in certain tissues over other tissues by judiciously selecting an effective echo time. This effective echo time is determined primarily by the actual echo time (TE) of the central, or low-order, views that dominate image contrast. For example, to enhance muscle tissue in the image of a human knee joint, the first spin echo signals may be encoded to a low-order phase encoding value in each shot because the T2 decay rate of muscle tissue is high and the shortest possible effective echo time (TE) is desired. On the other hand, to produce an image in which the fluids in the knee joint are enhanced, the low-order phase encoding views may be acquired from later echo signals which have a much longer echo time TE. The T2 decay rate of joint fluids is much less than that of muscle tissue, and as a result, these fluids will contribute proportionately more signal and their contrast will be enhanced in comparison with that of muscle tissue.

Detailed Description Text (13):
With the conventional FSE pulse sequence, the NMR echo signals 301-304 do not decay smoothly along the dashed line 315. Instead, the magnitude of the NMR signals 301-305 may oscillate significantly below this optimal T.sub.2 decay curve 315, particularly during the early NMR echo signals. This is illustrated in FIG. 4, where T.sub.2 is assumed to be very large, the vertical axis is NMR echo signal strength, and the horizontal axis is the number of the NMR echo signal in the shot. Each line represents the magnitude of the NMR echo signals produced by RF refocusing pulses having the indicated constant tip angle. The figure illustrates tip angles from .theta.=10.degree. to .theta.=170.degree., and it should be apparent from these that the signal level variation problem does not arise when perfect 180.degree. RF refocusing pulses are produced. Instead, as the tip angle is reduced below 180.degree., the oscillations in the early NMR echo signal magnitudes become very significant even at tip angles marginally less than 180.degree.. As the tip angle is further decreased, more NMR echo signals are affected before an equilibrium condition is reached, but the oscillations become less pronounced.

Detailed Description Text (26):
When the series of RF refocusing pulses are modified to produce a substantially constant NMR spin-echo signal amplitude (S), the modifications to the first few refocusing pulses is quite substantial. When applied to selective RF refocusing pulses, the above-cited copending application teaches that the single slice selective RF refocusing pulse is disected into a set of contiguous subslices and that each subslice in each RF refocusing pulse should be compensated to produce the

desired signal amplitude (S). When this is done, however, the shape of the first selective RF refocusing pulse is changed such that it has a larger bandwidth than the other RF refocusing pulses. In consequence its maximum amplitude of the time domain RF excitation field B.sub.1 is large and reaches quickly the maximum amplitude (or peak power) that the RF transmitter can play, particularly under heavily loaded conditions. This limits the selectivity of the RF refocusing pulses rather than the classical time transition-bandwidth product. We prefer not to increase the time-duration of the RF refocusing pulses to offset this limitation, since a goal in FSE imaging is to reduce the time between NMR echo signals.

CLAIMS:

1. An NMR system, the combination comprising:

means for generating a polarizing magnetic field;

excitation means for generating an RF excitation magnetic field which produces transverse magnetization in spins subjected to the polarizing magnetic field;

receiver means for sensing an NMR signal produced by the transverse magnetization and producing digitized samples of the NMR signal;

first gradient means for generating a first magnetic field gradient to phase encode the NMR signal;

second gradient means for generating a second magnetic field gradient to frequency encode the NMR signal; and

pulse control means coupled to the excitation means, first gradient means, second gradient means, and receiver means, said pulse control means being operable to conduct a fast spin echo pulse sequence in which a series of NMR echo signals are produced in response to a corresponding series of RF refocusing pulses produced by said excitation means, and in which a set of NMR echo signals following the first NMR echo signal in said series of NMR echo signals are stabilized to have a substantially similar amplitude (S) by altering the flip angle produced by RF refocusing pulses in said series, and the flip angle (.theta.) produced by the first RF refocusing pulse in said series is set to substantially the same flip angle (.theta.) as that of the second RF refocusing pulse in said series.

Previous Doc Next Doc Go to Doc#

L12: Entry 4 of 5 File: USPT May 24, 1994

DOCUMENT-IDENTIFIER: US 5315249 A
TITLE: Stabilized fast spin echo NMR pulse sequence

Abstract Text (1):
A fast spin echo NMR pulse sequence is modified to stabilize the magnitude of early NMR echo signals produced during each shot. Stabilization is accomplished by modifying the amplitude of the nutation angle produced in the spins by the corresponding RF refocusing pulses. When selective RF refocusing pulses are employed the slice is divided into subslices and the modifications are made separately to each subslice.

Brief Summary Text (2):
The field of the invention is nuclear magnetic resonance imaging methods and systems. More particularly, the invention relates to the reduction of image artifacts in fast spin-echo (FSE) pulse sequences by producing RF refocusing pulses which stabilize the magnitude of the acquired spin echo signals.

Brief Summary Text (10):
Both of these "fast spin echo" imaging methods involve the acquisition of multiple spin echo signals from a single excitation pulse in which each acquired echo signal is separately phase encoded. Each pulse sequence, or "shot," therefore results in the acquisition of a plurality of views and a plurality of shots are typically employed to acquire a complete set of image data. For example, a RARE pulse sequence might acquire 8 or 16 separate echo signals, per shot, and an image requiring 256 views would, therefore, require 32 or 16 shots respectively.

Brief Summary Text (13):
The present invention relates to an improved fast spin-echo pulse sequence in which the magnitude of an acquired NMR spin echo signal is stabilized by shaping the RF refocusing pulse which produces it. More particularly, in a fast spin echo pulse sequence one or more RF refocusing pulses are modified by changing their modulation envelope such that the magnitude of the NMR spin-echo signals does not oscillate. In a selective RF refocusing pulse this is accomplished by treating the RF refocus pulse slice profile as a series of subslices which each have a different tip angle and which each must be separately compensated.

Brief Summary Text (14):
A general object of the invention is to compensate the selective RF refocusing pulses in a fast spin echo sequence such that the NMR spin echo signals are stabilized in magnitude. It has been discovered that the amount of instability in the NMR echo signals is a function of the tip angle of the refocusing pulses. At a true 180.degree. tip angle there is no instability, but as the tip angle becomes smaller, the fluctuations in NMR echo signal magnitude increase. It is one discovery of the present invention that for a given echo signal magnitude, the magnitude and phase of the RF refocusing pulses in an FSE pulse sequence can be calculated such that all the resulting NMR spin echo signals may be stabilized. It is a further discovery of the present invention that since a selective RF refocusing pulse actually produces a range of tip angles over the thickness of the slice, then to properly stabilize the NMR spin echo signals produced by such selective RF refocusing pulses, the slice profile may be considered a set of

subslices at different tip angles. Accordingly, RF refocusing pulses may be produced to achieve excitation profiles that result in the stabilization of each subslice, and thus result in stabilization of the entire slice.

Brief Summary Text (15):
A general object of the invention is to stabilize the NMR spin echo signals in an FSE pulse sequence without increasing the scan time. No additional pulses need be added to the FSE pulse sequence. Instead, the shape of the RF refocusing pulse envelope is changed on as many of the initial refocusing pulses in the sequence as is necessary to provide the desired degree of stabilization. The modified pulse shapes may be calculated and stored in advance of the scan, and are played out in real time as the scan is conducted in the same manner as unmodified RF refocusing pulses.

Drawing Description Text (4):
FIG. 3 is a graphic representation of a fast spin-echo pulse sequence;

Drawing Description Text (7):
FIG. 6 is a graphic representation of the RF refocusing pulse magnitude required for each RF refocusing pulse in the FSE pulse sequence of FIG. 3 to provide stabilized NMR echo signals according to the present invention.

Detailed Description Text (2):
Referring first to FIG. 1, there is shown in block diagram form the major components of a preferred NMR system which incorporates the present invention and which is sold by the General Electric Company under the trademark "SIGNA". The overall operation of the system is under the control of a host computer system generally designated 100 which includes a main computer 101 (such as a Data General MV7800). The computer has associated therewith an interface 102 through which a plurality of computer peripheral devices and other NMR system components are coupled. Among the computer peripheral devices is a magnetic tape drive 104 which may be utilized under the direction of the main computer for archiving patient data and images to tape. Processed patient data may also be stored in an image disc storage device designated 110. The function of image processor 108 is to provide interactive image display manipulation such as magnification, image comparison, gray-scale adjustment and real-time data display. The computer system is provided with a means to store raw data (i.e. before image construction) utilizing a disc data storage system designated 112. An operator console 116 is also coupled to the computer by means of interface 102 and provides the operator with the means to input data pertinent to a patient study as well as additional data necessary for proper NMR system operation, such as calibrating, initiating and terminating scans. The operator console is also used to display images stored on discs or magnetic tape.

Detailed Description Text (6):
The gradient coil assembly 136 and the RF transmit and receiver coils 138 are mounted within the bore of the magnet utilized to produce the polarizing magnetic field. The magnet forms a part of the main magnet assembly which includes the patient alignment system 148. A shim power supply 140 is utilized to energize a shim coil associated with the main magnet and which are used to correct inhomogeneities in the polarizing magnet field. In the case of a superconductive magnet, the main power supply 142 is utilized to bring the polarizing field produced by the magnet to the proper operating strength and is then disconnected. The patient alignment system 148 operates in combination with a patient cradle and transport system 150 and patient positioning system 152. To minimize interference from external sources, these NMR system components are enclosed in an RF-shielded room generally designated 144.

Detailed Description Text (11):
Referring particularly to FIG. 3, a conventional fast spin echo NMR pulse sequence,

known as a 2DFT RARE sequence is shown. For clarity, only four echo signals 301-304 are shown in FIG. 3, but it can be appreciated that more are produced and acquired. These NMR echo signals are produced by a 90.degree. RF excitation pulse 305 which is generated in the presence of a G.sub.z slice select gradient pulse 306 to provide transverse magnetization in a slice through the patient. This transverse magnetization is refocused by each selective RF refocusing pulse 307 to produce the NMR spin echo signals 301-304 that are acquired in the presence of G.sub.x readout gradient pulses 308. Each NMR spin echo signal 301-304 is separately phase encoded by respective G.sub.y phase encoding pulses 309-313. The magnitude of each phase encoding pulse is different, and it is stepped through 256 values to acquire 256 separate views during a complete scan. This enables an image having 256 separate pixels in the y direction to be reconstructed. Each NMR spin echo signal is acquired by digitizing 256 samples of each signal. As a result, at the completion of a scan for one image, 16 shots (256/16=16) of the pulse sequence of FIG. 3 have been executed and a 256 by 256 element array of complex numbers have been acquired. An 20 image is reconstructed by performing a 2D Fourier transformation on this image data array and then calculating the absolute value of each resulting complex element. A 256 by 256 pixel image is thus produced in which the brightness of each pixel is determined by the magnitude of its corresponding element in the transformed array.

Detailed Description Text (12):
Referring still to FIG. 3, the T.sub.2 decay in the NMR spin echo signals 301-304 is illustrated by the dashed line 315. The rate of decay is different for different tissue types and a common strategy in FSE NMR imaging is to enhance the contrast in certain tissues over other tissues by judiciously selecting an effective echo time. This effective echo time is determined primarily by the actual echo time (TE) of the central, or low-order, views that dominate image contrast. For example, to enhance muscle tissue in the image of a human knee joint, the first spin echo signals may be encoded to a low-order phase encoding value in each shot because the T.sub.2 decay rate of muscle tissue is high and the shortest possible effective echo time (TE) is desired. On the other hand, to produce an image in which the fluids in the knee joint are enhanced, the low-order phase encoding views may be acquired from later echo signals which have a much longer echo time TE. The T.sub.2 decay rate of joint fluids is much less than that of muscle tissue, and as a result, these fluids will contribute proportionately more signal and their contrast will be enhanced in comparison with that of muscle tissue.

Detailed Description Text (13):
With the conventional FSE pulse sequence, the NMR echo signals 301-304 do not decay smoothly along the dashed line 315. Instead, the magnitude of the NMR signals 301-305 may oscillate significantly below this optimal T.sub.2 decay curve 315, particularly during the early NMR echo signals. This is illustrated in FIG. 4, where T.sub.2 is assumed to be very large, the vertical axis is NMR echo signal strength, and the horizontal axis is the number of the NMR echo signal in the shot. Each line represents the magnitude of the NMR echo signals produced by RF refocusing pulses having the indicated constant tip angle. The figure illustrates tip angles from .theta.= 10.degree. to .theta.= 170.degree., and it should be apparent from these that the signal level variation problem does not arise when perfect 180.degree. RF refocusing pulses are produced. Instead, as the tip angle is reduced below 180.degree., the oscillations in the early NMR echo signal magnitudes become very significant even at tip angles marginally less than 180.degree.. As the tip angle is further decreased, more NMR echo signals are affected before an equilibrium condition is reached, but the oscillations become less pronounced.

Detailed Description Text (26):
However, as indicated above, the present invention is also applicable where selective 180.degree. RF refocusing pulses are employed in the FSE sequence. Referring again to FIG. 5, in a conventional slice select profile 319 a slab of spins over a region indicated as subslice 320 is excited at the desired 180.degree.

nutation angle. However, this is not true in the transition regions 330 on each edge of this central subslice 320. Instead, these transition regions 330 can be viewed as a set of separate subslices having separate tip angles. Unless stabilized, the spins in these transition regions 330 will produce NMR signal components which vary in amplitude quite significantly during the early portion of each FSE shot. The contribution which these transition spins make to the total NMR echo signal will vary as a function of slice thickness and slice profile, however, it is a significant amount and the resulting echo signals will oscillate in magnitude.

CLAIMS:

1. An NMR system, the combination comprising:

means for generating a polarizing magnetic field;

excitation means for generating an RF excitation magnetic field which produces transverse magnetization in spins subjected to the polarizing magnetic field;

receiving means for sensing an NMR signal produced by the transverse magnetization and producing digitized samples of the NMR signal;

first gradient means for generating a first magnetic field gradient to phase encode the NMR signal;

second gradient means for generating a second magnetic field gradient to frequency encode the NMR signal; and

pulse control means coupled to the excitation means, first gradient means, second gradient means, receiver means, said pulse control means being operable to conduct a fast spin echo pulse sequence in which a series of NMR echo signals are produced in response to a single RF excitation pulse followed by a corresponding series of RF refocusing pulses produced by said excitation means, and in which said NMR echo signals are stabilized to a substantially smoothly decaying amplitude by altering the flip angle produced by one or more of the initial RF refocusing pulses in said series.

2. An NMR system, the combination comprising:

means for generating a polarizing magnetic field;

excitation means for generating an RF excitation magnetic field which produces transverse magnetization in spins subjected to the polarizing magnetic field;

receiver means for sensing an NMR signal produced by the transverse magnetization and producing digitized samples of the NMR signal;

first gradient means for generating a first magnetic gradient to phase encode the NMR signal;

second gradient means for generating a second magnetic field gradient to frequency encode the NMR signal;

third gradient means for generating a third magnetic field gradient to select a slice of said spins comprised of a plurality of adjacent subslices of said spins which are transversely magnetized by said excitation means; and

pulse control means coupled to the excitation means, first gradient means, second gradient means, third gradient means and receiver means, said pulse control module means being operable to conduct a fast spin echo pulse sequence in which a series

of NMR echo signals are produced in response to a single RF excitation pulse followed by a corresponding series of selective RF refocusing pulses produced by said excitation means concurrently with corresponding slice select pulses produced by said third gradient means, and in which said NMR echo signals are stabilized to a substantially smoothly decaying amplitude by altering the flip angle produced by said selective RF refocusing pulses for one or more subslice components.

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L13: Entry 1 of 2 File: USPT Jul 24, 2001

US-PAT-NO: 6265873
DOCUMENT-IDENTIFIER: US 6265873 B1

TITLE: Non-CPMG fast spin echo MRI method

DATE-ISSUED: July 24, 2001

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
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US-CL-CURRENT: 324/309; 324/307

Full | Title | Citation | Front | Review | Classification | Date | Reference | | | Claims | KWIC | Draw D

☐ 2. Document ID: EP 1037067 A1, US 6265873 B1, JP 2000262489 A

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TITLE: Production method for image using fast spin echo in MRI system

Full | Title | Citation | Front | Review | Classification | Date | Reference | | | Claims | KWIC | Draw D

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INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
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US-CL-CURRENT: 324/309; 324/307

Full | Title | Citation | Front | Review | Classification | Date | Reference | | | Claims | KWIC | Draw De

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